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SURVEYS OF THE EARTH'S RESOURCES AND ENVIRONMENT BY SATELLITES

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Dr. William Nordberg

ABSTRACT

Two of NASA's recent satellites have made very significant contributions to the systematic surveying of processes and phenomena occurring on the surface of the earth. ERTS-1, which has operated almost flawlessly since August 1972, is providing registered, multispectral images of about 5 million square kilometers of the earth's surface every day. These images are being used to make thematic maps on scales of at least 1:250,000 almost instantly. They have been used for the assessment of available water resources and for a nationwide survey of water impoundment. Maps of landforms and tectonic features made from ERTS images have demonstrated their utility in facilitating mineral and petroleum exploration, expecially in making such exploration more cost effective. Other applications of ERTS-1 images throughout the world have been in land use planning; crop, forest and rangeland inventory; assessment of flood, earthquake and other environmental hazards; monitoring coastal processes and the environmental effects of industrial effluents and of air pollution.

Images of the earth's surface, although with the crude spatial resolution of 30 x 30 km, were extended into the microwave spectrum for the first time with NIMBUS 5 in 1973. This has resulted in our ability to map, daily and synoptically, the distribution and types of ice covering the earth's polar caps. Some gross characteristics of global soil moisture distributions can also be derived from these observations.

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INTRODUTION

Since the launching of the first Earth Resources Technology Satellite (ERTS), which took place more than two years ago, many words have been spoken and written about this new marvel of our space technology. Some have claimed that this method of observing our planet will be a panacea to finding minerals, predicting earthquakes, harvesting crops and ridding the world of the plagues of pollution and the abuse of land resources, while cynics have called remote sensing from satellites just another tinkertoy of the engineers. Obviously, the truth lies somewhere between these two extremes. It is the intent of this presentation to put this argument in a realistic perspective, and to discuss, at the hand of a few examples, the potential and promises of observing the earth from the vantage point of space.

Furthermore, it is intended to bring this argument, of just how good and how useful remote sensing of the earth from space is, before an audience that carries considerably more weight in judging this issue than the aerospace community and the bureaucrats who have argued it so far. Ironically, the so-called user community, the decision makers, whom one would expect to welcome with open arms--and open minds--any advanced technique that makes their jobs easier, more reliable and more economical, have remained relatively aloof of the question whether earth surveys from space are useful or not. Many of those who should be concerned with the exploration and management of mineral and water resources, with land use planning or with environmental protection, are generally unaware of the vast, new information that is available to them, virtually for the asking.

The first ERTS has by now produced more than 100,000 multispectral images of almost every land mass on earth. Land forms, land use practices, and water features of every continent have been observed several times during the past two years with accuracies that are commensurate with map scales of 1:250,000. With some additional effort, thematic maps on scales of up to 1:60,000 can be produced from the satellite images. These images can be purchased at nominal cost from several federal data centers by anyone who asks for them. One of them is the U. S. Department of Interior, EROS Data Center, Sioux Falls, South Dakota, 57198 (Telephone 605/594-6511).

The perspective of the satellite images is such that vast areas, such as entire mountain ranges, watersheds, States and indeed entire continents can be mapped nearly synoptically. The cost of producing these relatively large scale, thematic, synoptic maps from ERTS images is orders of magnitudes less than the cost of conventional techniques, such as aerial surveys. ERTS provides a sequence of uniformly illuminated, essentially planimetric, vertical views of the Earth's surface. The images can be readily joined together in mosaics which are very close to being orthographic. This greatly increases the synoptic character of the imagery and extends the assessment of contextual relationships to regional proportions, as is shown in Figure 1, where ERTS-1 images obtained on several consecutive satellite passes, were combined into a mosaic of the entire state of Nevada. Such mosaicking can be extended almost arbitrarily and the Soil Conservation Service of the U. S. Department of Agriculture has now produced a mosaic that embraces the entire continental United States (Figure 2). In its original 1:1,000,000 scale, this mosaic covers a display area of 24 feet (east-west) by 10 feet (north-south). Synoptic, thematic mapping of such immensely large areas has resulted, for the first time, in a uniform photobase of the Earth's surface to integrate physiographic or geologic provinces up to continental scales.

Surface features of North America have been observed by ERTS-1 about 10-35 times on the average during the first 30 months of the satellite's life. The frequency of useful observations depends on cloud cover. Consistently cloud-free areas such as the Southwestern U. S. were imaged as many as 35 times, while perennially cloud-covered regions such as the Gulf Coast or the Florida Peninsula may have been seen only 10-15 times by the satellite in that period. Such sequential observations are extremely important, especially if one wishes to determine, for example, the water runoff from diminishing snow cover in a mountainous watershed, or the position of a surging glacier which threatens unstable conditions in the damming of a river valley. They are also important for the observation of seasonal and long-term coastal processes which cause sedimentation and erosion and have practical application to habor and shoreline maintenance, ocean waste disposal, marine pollution, and fisheries. Sequential observation of surface mining operations can provide accurate and timely data on mined acreage and the status of land reclamation activities.

In contrast to conventional aerial photographs, ERTS images are generated from digital electronic signals which measure the intensity of sunlight in four spectral bands, detected by a scanning telescope and an array of photo-electric detectors on-board the satellite. The four spectral bands cover the visible green and red (0.5 to 0.6 and 0.6 to 0.7 μm) and two near-infrared bands (0.7 to 0.8 and 0.8 to 1.1 μm). The sensor output is telemetered from the satellite to ground stations, and recorded on tape. From the magnetic tapes, black-and-white images are generated for each of the four spectral bands. The polychromatic or multispectral nature of the images permits the identification or measurement of the quality and composition of water, the potential water content of snow, the moisture and possible composition of soils, the types and state of vegetation cover, and factors relating to stresses on the environment. For example, water is clear, where it appears dark in all four spectral bands; it is sediment laden or contains high concentrations of nutrients, where it appears bright in the short wavelengths and dark in the long wavelengths. Vigorous vegetation appears very dark in the visible spectrum but is almost as bright as snow in the infrared, while less vigorous or diseased vegetation becomes brighter in the visible and darker in the infrared. Images in the separate spectral bands can be overlaid in color composites which display the spectral contrasts in varying shades of blue, green and red and permit, readily, the identification and measurement of these botanical, hydrographic, environmental or cultural features on the earth's surface. In other more sophisticated techniques, data from the tapes are fed directly into computer-controlled displays for enhancements for measurements of certain desired characteristics.

GEOLOGICAL ANALYSES OF ERTS IMAGES

The applications that have been derived from the ERTS-1 images are so diversified and cover so many disciplines, that it is not possible to mention all of them in this presentation. Therefore, only a few examples will be discussed here ; namely some illustrating the potential of land-form observations for mineral exploration and for the assessment of geological hazards, and others showing the efficiency and cost effectiveness of using thematic maps made from the satellite pictures in decisions or settlements involving environmental protection and reclamation. Many of the other applications, such as land-use planning and land-value assessments, crop and rangeland productivity surveys, water quality and marine resources surveys, flood plain mapping and water run-off predictions are beyond the scope of this presentation.

The greatest potential of ERTS images for mineral exploration rests on our ability to map synoptically the geomorphology and general geological environment of very large areas. Two phenomena are of particular significance in this context:

(1) linear or circular features can be identified and mapped; they can be: (a) of tectonic origin, such as faults or fractures, which are thought to be indicative of mineral deposits, particular, where these lineaments intersect; or (b) revealing land forms such as salt domes which might be indicative of petroleum.

(2) color tone differentiations in the images may: (a) permit the delineation of rock types, vegetation or soil differences, each again leading to possible conclusions regarding mineral deposits; or (b) be related to oxidation or other chemical reactions on the surface which may imply mineralization or petroleum deposits.

A principal result from the ERTS images has been the recognition of new structural information in the form of numerous linear features, ranging from 1-2 kilometer up to several thousand kilometers in length. Linears are identified by such indicators as: tonal discontinuities, established usually as boundaries between opposing light and dark areas in a scene; bands of variable width, set in contrast to their borders and/or adjacent areas; alignment of topographic forms, often emphasized by shadowing; alignments of drainage patterns; association of vegetation along linear trends; co-alignment of cultural features, e.g., farms, road patterns, etc., with underlying structural and/or topographic control. Not all of these features identified as linears are geologic in origin, of course, and all must be carefully checked against available maps, photos and ground surveys to properly ascertain their significance. Circular features have been particularly prominent in ERTS images. Many of these are volcanic or intrusive in nature, and others may mark buried structures such as salt domes. Some circular features have been recognized in ERTS images as meteoric impact craters.

W. D. Carter, U. S. Geological Survey, did a preliminary linear and circular feature analysis of the ERTS-1 image mosaic of the continental U. S., looking at stream patterns, topography, shadows and tonal differences that could possibly be related to geologic structure (1). His interpretation gave a broad overview which indicated the possibility of discovering many new structural features that have not yet been identified in standard geologic mapping. The interpretation served to establish a new USGS project in which mosaics at 1:1,000,000 are studied in detail by three independent interpreters. Maps showing relative confidence of interpretations of each of the features identified will be distributed to Survey geologists specializing in structural geology and geophysics in various regions of the U. S. for evaluation and correlation with existing evidence. Hopefully the maps will provide new ideas on structural geology and assist the search for mineral energy sources.

In another aspect of regional tectonic studies using ERTS images, investigators at the University of Wyoming (2) have related the structure of mountain ranges with that of adjacent basins. The ERTS images allow rapid compilation of orientations for major faults and joints in the exposed cores of mountains and similarly rapid assessment of the axial trends of basin folds. Such analysis revealed a strong similarity between structural orientations in the Laramie Range and the Laramie basin, suggesting a common genesis. Marked dissimilarities showed up, however, in studies of structural trends in the Bighorn and Pryor Mountains. The speed with which this type of mapping can be done is illustrated in Figure 3. Interpretations of Wind River Range structure, laboriously compiled in the field by Dr. R. Parker over a period of five years, are shown at left. An updated compilation for the entire range, shown on the right, was completed in a matter of hours. Although this map is a preliminary evaluation, some confidence in its accuracy is afforded by evidence of fracturing found at several field-checked locations.

MINERAL AND PETROLEUM EXPLORATION

A study of ERTS images of northern Alaska (3), which revealed an interesting alignment of lakes over distances of several hundreds of kilometers has led to speculations about the extension of petroleum exploration in Northern Alaska. Lakes in the Arctic Coastal Plain are dominantly elongate, with their long axes parallel and trending about N 9°W. This is believed to be erosion controlled. However, an analysis of ERTS-1 imagery revealed an additional east-west-trending alignment of lakes extending over a much larger region and not previously recognized on aerial photographs or in field studies. In addition, the alignment of many small lakes forms ellipses superimposed on the regional lineation. When combined with the sparse magnetic and gravity survey data for the region, these lineations suggest heretofore unsuspected structures may be concealed beneath the mantling Quaternary Gubik Formation and that favorable reservoir beds may occur in the area. In an earlier investigation, E. Lathram (3) of the U. S. Geological Survey verified the presence of sets of intersecting NE- and NW-trending regional lineaments in Alaska. Based on the occurrence of these regional fractures, Lathram suggested that mineral emplacement might have occurred at the intersections of these fractures. The results is an alternate hypothesis for mineral emplacement in Alaska than was previously held. This will probably stimulate interest in exploration efforts in areas which were long regarded as non-productive.

Duane Preble and W. D. Carter, of the U. S. Geological Survey, identified linear and circular anomalies in the Louisiana-Mississippi area on the basis of vegetation, stream drainage patterns and soil tones (4). Eleven small circulars, one with a diameter of 70 kilometers, were identified near known salt domes from which oil and gas are produced. Some of the newly found suspected salt domes correspond to negative gravity anomalies. Others, where such data are not available, are to be surveyed with a field gravimeter to determine if they are worthy of more detailed exploration. The linear features may possibly be related to subsurface faults which could serve as control for accumulation of oil and gas.

E. Rich (5) of Stanford University and M. Abdel-Gawad (6) of North American Rockwell Corp. and I. Bechtold of Bechtold Satellite Technology Corporation (7) have correlated mining localities in California and Nevada with lineaments observed in the ERTS images. Abdel-Gawad correlated mercury mining localities with a newly discovered set of transverse faults in the California Coast Ranges, Bechtold demonstrated a similar correlation between fissures in the Lake Mead area and gold, silver and other metallic ore deposits.

Many shallow mineral deposits give rise to distinctive surface stains (gossans and blooms) caused by alteration or secondary enrichment. If broad enough, some of these stains may be detactable as color-brightness anomalies. In a study of such color tone phenomena, A. F. H. Goetz, Jet Propulsion Laboratory, and L. C. Rowan, U. S. Geological Survey, have applied band ratio techniques to the search for iron oxides (8). Confirming from field and laboratory spectrometer measurements that limonite has a spectral response quite different from most other common minerals, the investigators concluded that this response can be detected with ERTS by imaging the ratios of several of the spectral bands rather than by displaying the bands themselves, as is commonly done. They have analyzed an ERTS image of central Nevada that includes the Goldfield mining district and have found that the distinctive spectral signatures in the images correlate with those mineralized areas around Goldfield where surface iron stains were known before. In addition, they have detected these signatures in adjacent areas where mineralization was not previously known. Insofar as gossans are indicators of potential mineralization, this enhancement technique for revealing the distribution of hydrous iron oxides in ERTS images, if it bears up under further testing, now stands as a major breakthrough in mineral prospecting.

Soil coloration is also known to occur in the vicinity of petroleum deposits where surface minerals have been chemically altered by combination with escaping hydrocarbons. To test the capability of ERTS to detect this phenomenon, imagery of the Anadarko basin in Oklahoma was analyzed for tonal differences around known gas and oil producing areas (9). On one color composite image, 76 features were classified as geomorphic or tonal anomalies and "hazy" areas. The "hazy" areas appear as if image detail had been smudged or partially erased. Of these 76 anomalies, 59 correlate with producing oil and gas fields, 11 are of known but non-producing structures, and the remaining 6 could not be correlated with known features. Further study is underway at NASA to test the validity and applicability of the association of these anomalies with gas and oil occurences.

GEOLOGICAL HAZARDS AND USE OF ERTS IMAGES IN CIVIL CONSTRUCTION PROJECTS

Mapping of regional lineaments with ERTS images has resulted in delineating seismic hazards not otherwise recognized. Abdel-Gawad discovered evidence of recent movement along faults in an area of Californa that had long been considered to be inactive (6). L. Gedney of the University of Alaska constructed a mosaic of central Alaska using six ERTS images (10), which clearly revealed the presence of new sets of lineaments that correlated well with the distribution of shallow-focus earthquake epicenters in that region. An active leg of the Denali fault was found to lie close to a proposed bridge site over the Yukon River, and the proposed path of the Alaskan oil pipeline.

Dan Krinsley, of the U. S. Geological Survey, used sequential ERTS images of the Great Kavir area in Iran to delineate seasonally wet, rough and unstable ground. This analysis resulted in the selection of a preliminary road alignment that would take advantage of the best terrain and considerably shorten the present route between northern and central Iran (11).

ENVIRONMENTAL IMPACT

The use or ERTS in the observation of the effect of man's activity on the natural evironment is illustrated in Figure 4. The very light tones in the center of this enlarged portion of an ERTS image (1:250,000 scale) shows the destruction of vegetation around a 90 square kilometer area near Ducktown, Tennessee, by copper mining operations, including fumes from the open roasting of ore and timber cutting. The light area is indicative of almost total denudation. Parts of the area are now being reclaimed by the planting of pine trees and grasses, and natural grasses and trees are returning in response to control of smelter gases (12). ERTS images have also revealed the denuding of vegetation near Wawa, Ontario, where prevailing winds carrying sulfur dioxide fumes from a local sintering plant have caused vegetation damage similar to that around Ducktown (13). ERTS images have permitted the delineation and measurement of the degree of vegetation damage in a most economical, rapid and objective manner.

In the Chicago-Gary area, particulate plumes from steel mills observed in the ERTS images have been traced across Lake Michigan during the 1972/73 winter season (14). The plumes, carrying condensation nuclei, were observed to trigger dense stratus cloud cover which resulted in snowfall 200km downwind on the western shore of Michigan.

The extent of coal strip mining and the progress of reclamation is being monitored in western Maryland by NASA scientists (15). Acreage figures are being compiled for seven land use classes, ranging from stripped earth to fully reclaimed land. This monitoring technique provides more accurate and complete data than are available from conventional surveys, since data collected by State agencies cover only post-1967 mining activity and do not include areas of backfilling and contouring around the boundaries of the mines. Sequential ERTS coverage provides timely and complete status reports on reclamation of the mined areas.

CONCLUSION

A vast data base has been accumulated with the first ERTS. This data base has barely been tapped and is ready to be exploited. Early research investigations sponsored by NASA and other Government agencies have demonstrated the validity and utility of this data base to the dynamic inventoring of the world's water and food resources, to the more efficient exploration of mineral, and possibly fuel resources, to the planning of land use and civil projects, and to the quantitative assessment of the environmental impact of many of our activities. The ultimate users of this data base, who stand to benefit most from this investment made by the Government, however, have not yet warmed up to this new technique of earth surveys, leave alone, having taken full advantage of its potential.

Although NASA will launch a second ERTS in January 1975, there will not be a continuation of this program after the second satellite, unless there is a real demand to use this data base by those concerned with exploration, hazard assessment and environmental impact prediction. If this demand does not materialize, the paradoxical situation might arise that in a few years when the users will begin to realize the value of this methodology and will get used to the continuing and practically free data flow, the Government will have cancelled the program for lack of interest.

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FIGURES

Figure 1.

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OF POOR QUALITY

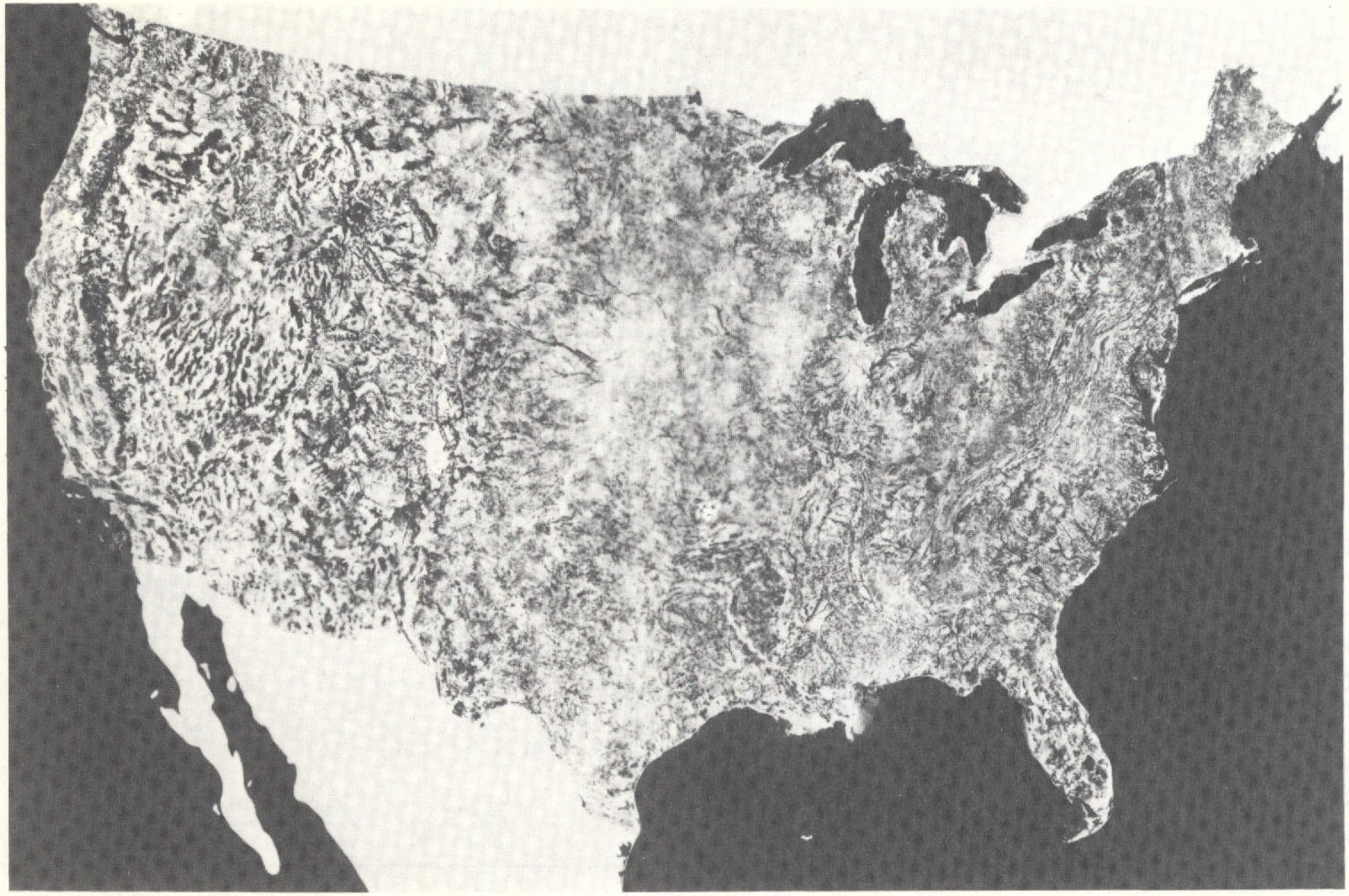
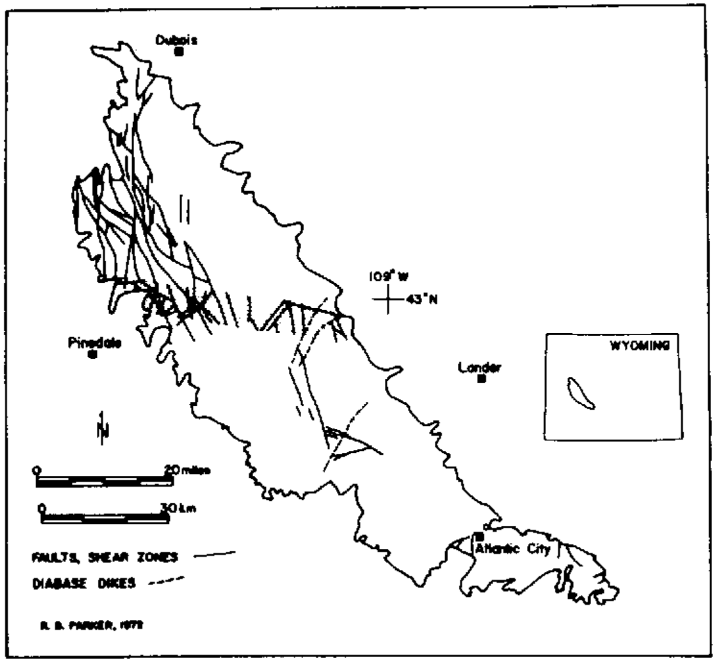


Figure 2.



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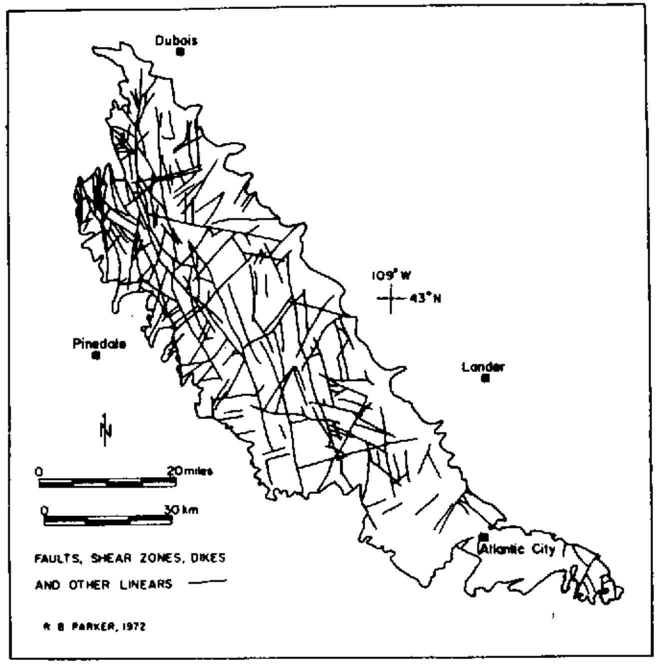

Observed by ERTS-1

Figure 3.

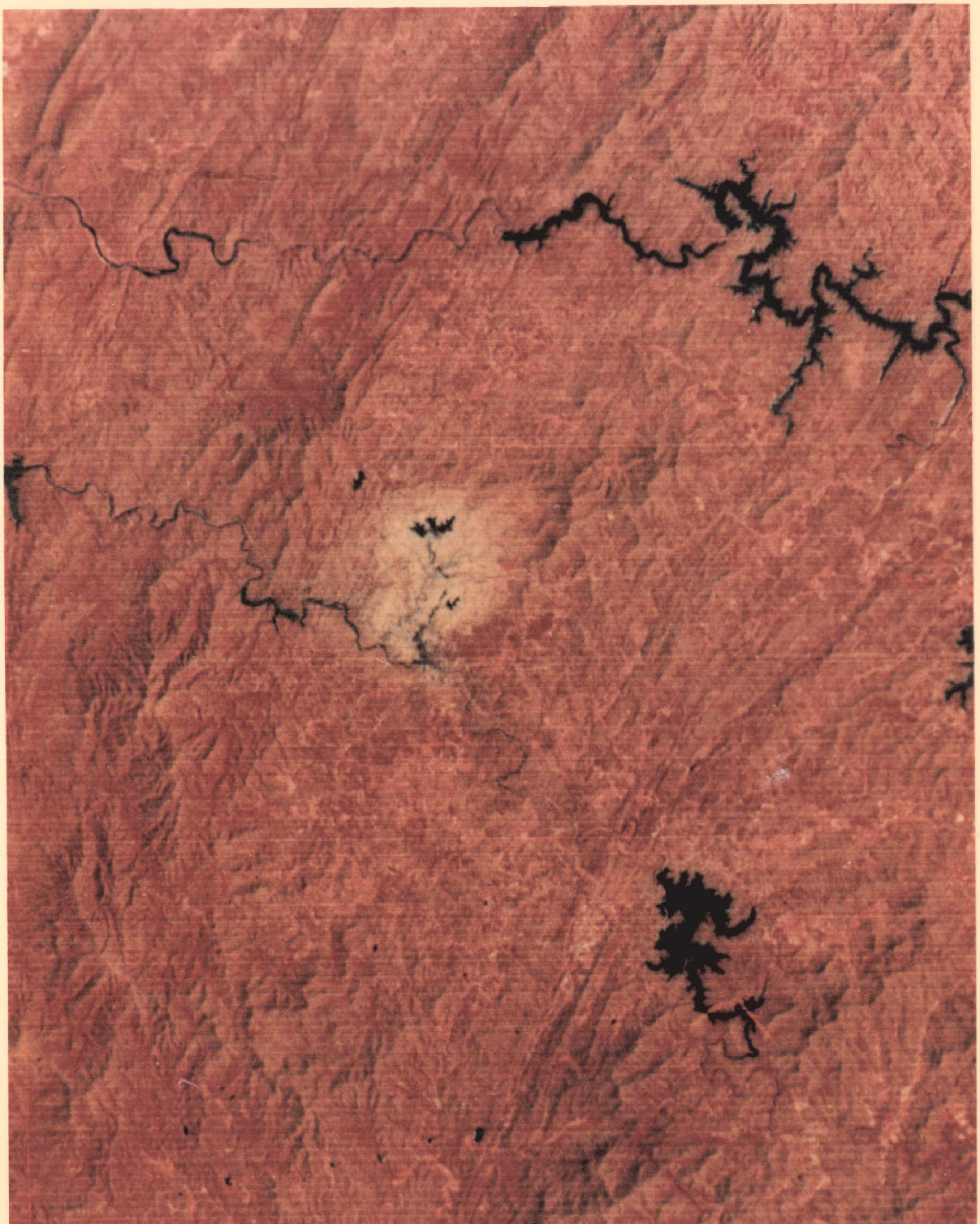

Figure 4